DENSITY OF MOLTEN GLASS

BY

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THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

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ENTITLED " Density of Molten Glass"

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE

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DENSITY OF MOLTEN GLASS

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I. INTRODUCTION

The importance of tne determination of the density of molten glass can be discussed from two aspects. First, from the purely scientific point of view, and secondly, from the practical point of view.

The art of glass making has been known since ancient times. But since then there has not been very much advancement until rather modern times. People now-a-days know how to make glass, but the reactions in various steps during its course of manufacture are not completely known. Only little work has been done on the various properties of glass at high temperatures. No work has been done on the density of molten glasses. Thus although the art of glass manufacture is quite perfect, yet the knowledge of its underlying facts is still incomplete. Work of this kind will, of course, be of some value for the literature.

From the practical point of view, density has a close relation with viscosity, surface tension, and other physical constant By knowing the densities at high temperatures, we can figure out the coefficient of expansion at different temperatures. This work has been carried on to 600°C by C.G.Peters and C.H.Cragoe.*

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* J.Opt. Soc.Am.4, 105-44, 1920

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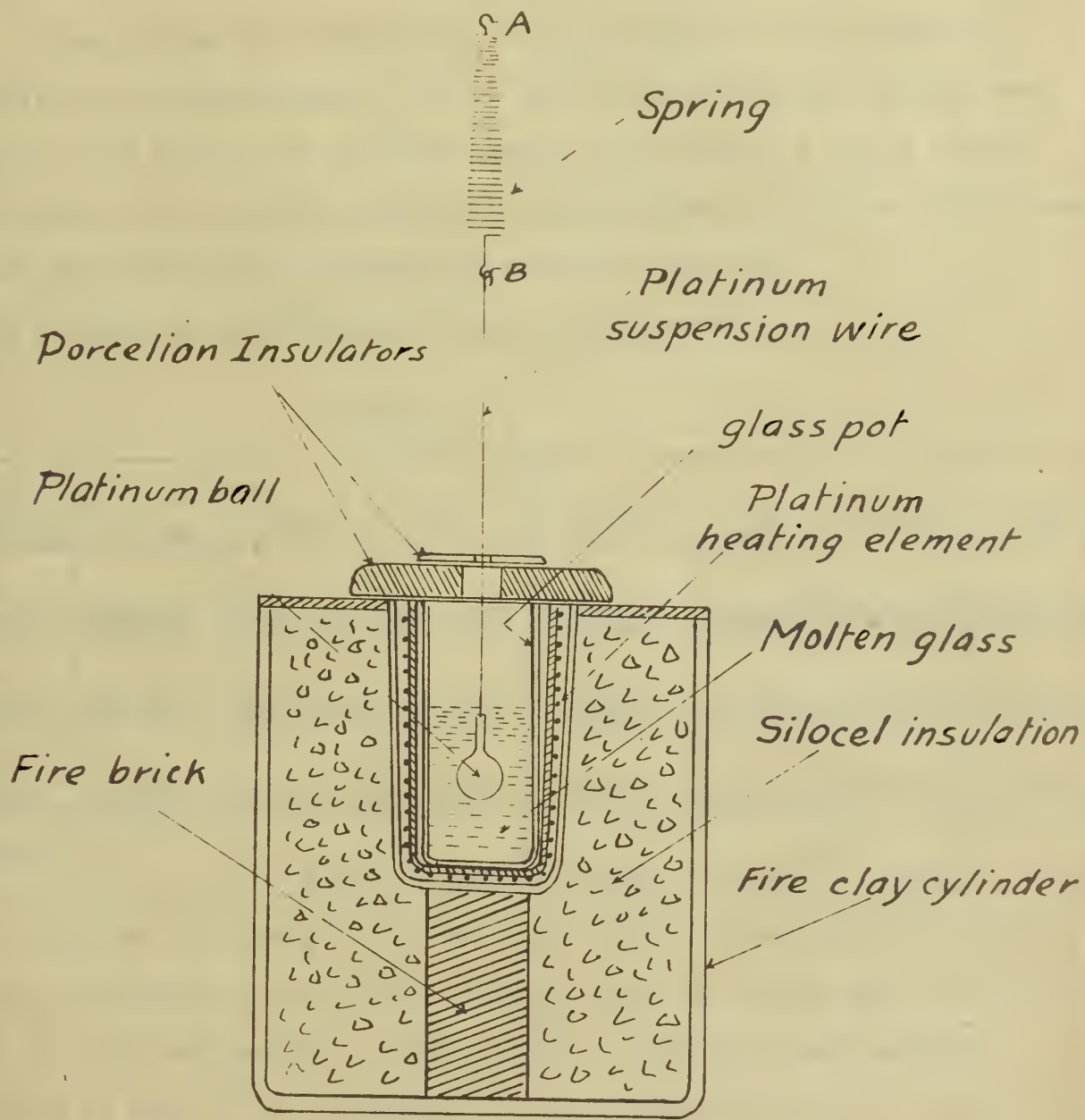
The density of molten glass is an important factor in the process of feeding the molten glass to the molds or machines for making different articles.

II. EXPERIMENTAL PART.

The method used for the determination of the density of molten glass was to immerse a platinum sphere of known volume in the fluid, and the loss of weight was measured . The density was then obtained by a simple process of division with a few necessary corrections. The sphere was suspended on a Jolly spring balance with a fine platinum wire. In order to diminish the effect of surface tension, which was one source of error, as much as possible, and at the same time to have the wire strong enough to hold the weight at high temperatures, wire of 0.3 mm. in diameter was used. The furnace was heated by electricity by passing current through a platinum resistance coil. As shown on the diagram, the furnace consists of a long porcelain cylinder with platinum heating element wound outside. The glass pot in which the glass was melted was of similar construction, but smaller in size so that it would just fit into the furnace. One more porcelain pot a little larger than the heating pot was used to protect the latter and facilitate the task of mending in case any accident happened to the furnace. Now the whole apparatus was put in a large fire clay cylinder containing a lot of insulating materials, such as silocel and calcined kaolin. In order to prevent radiation loss on the top, a well fitted porcelain cover was used. The cover consisted of two equal semi-circular discs with a hole in the center so that we could see what was going on during the run. The temperature was measured by a platinum-rhodium thermocouple inserted between

the glass pot and the heating cylinder. Now the glass in small pieces was charged into the pot with the thermocouple fitted in position, and the current turned on. After the glass became quite fluid the platinum ball was inserted. Care was taken not to immerse too much of the wire beneath the surface, but just enough so that the ball was completely immersed. The temperature of the glass was raised to a little above 1400°C and kept at this temperature for a few moments in order to secure equilibrium. Then readings were ready to be taken. The distance or stretch between two definite points, A and B (see the diagram) on the spring was read by means of a cathetometer to 0.02 mm. Readings were taken at 1200°, 1300°, and 1400° respectively. A reading was first made at 1400°, and then the furnace was cooled down very slowly to 1300°C, maintained at this temperature, when another reading was taken. A similar reading was made at 1200°C. After this, the temperature was again raised and another set of readings obtained in order to check the first set of readings.



FURNACE AND SPRING FOR THE DETERMINATION OF THE DENSITY OF MOLTEN GLASS

III. CALIBRATION OF THE SPRING.

The spring was calibrated by applying to it successively a series of known weights, and at each time after the spring came to rest, the amount of stretch between the points A and B on the spring was read, and the amount of elongation by one gram additional weight was obtained by averaging all the readings.
Table I shows a calibration of the spring used.

Table I

Weight on spring	10 gm.	10.5	11	11.5	12	12.5	13.
Upper reading	104.082	104.082	104.082	104.082	104.082	104.082	104.082
Lower reading	80.764	80.320	79.880	79.435	78.986	75.543	77.095
Total Stretch	23.318	23.762	24.202	24.647	25.096	25.537	25.987
Elongation		0.444	0.440	0.445	0.449	0.441	0.437

The wt. of the pan (0.5956 gm.) used for holding the weights was not included on the table because what we wanted was the elongation of one gram weight. The weight of the pan was measured because it had to be included for the calculation of the check weight.

Now immediately after finishing each determination, the weight of the platinum ball in the molten glass was calculated by means of this table and a metal button of any kind having its weight equal to the calculated value was weighed out. Without

letting the spring go back, the platinum ball with its suspension wire was removed from the spring and the check weight put on it. After the spring came to rest, the reading of the stretch between the points A and B on the spring was again made.

By comparing this amount of stretch with that of the actual run, the difference was interpolated and added or subtracted from the known weight, as the case may be. In this way any source of error such as that due to fatigue of the spring, or to change of temperature of the spring tending to alter the amount of stretch from its normal value, was eliminated

IV. CALCULATIONS

The volume of the platinum ball was obtained by Archimede's water displacement method. If the water in which the platinum ball was weighed, were at 4°C, then loss of weight in water would give us its volume directly. But if it were not at 4°C, the loss was divided by the density of water at the corresponding temperature. Necessary corrections were applied to the calculation. The volume of the platinum ball at high temperatures was obtained by applying the following equation:

$$V_t = (1 + \alpha t) V_o$$

where V_t = the volume at temperature = t

V_o = Volume of platinum ball at 0°

α = the cubical coefficient of expansion

The volume of the platinum ball calculated from the above equation at temperatures 1200°, 1300° and 1400°C was 0.6056, 0.6064, and 0.6080 cc, respectively. After securing the readings at various temperatures, the weights corresponding to the stretches were calculated and a check weight of metal having the same weight was applied to the spring. From this we obtained the true weight of the platinum ball in glass with one more correction, i.e. the surface tension effect of the molten glass, which was exerted on the suspension wire and helped to pull down the spring. The surface tension of the glasses was determined by Mr.E.E.Libman in his doctorate thesis, and it varies from 140 to 170 dynes per centimeter. Since this was not a big amount the average value

of 155 dynes per centimeter was used in this case. The following formula was used in calculating the results:

$$\text{Density} = \frac{\text{Wt. in air} - (\text{Wt. in glass} - \text{Surface tension corr.})}{\text{Volume of the pt. ball}}$$

The density of thirteen samples of glass having the following composition was determined.

TABLE II. Composition of the Glasses

No.	SiO_2	Na_2O	CaO
2	82.3	17.7	
3	70.0	30.0	
4	60.0	40.0	
5	62.7	14.7	22.6
6	60.5	20.0	19.5
7	60	30	10
8	70	20	10
9	52.5	40.0	7.5
10	70.0	10	20
12	72	14.5	13.5
13	73.5	16.5	10.0
15	67.5	15.5	17.0
16	65	20	15.0

V. RESULTS FROM EXPERIMENTS.

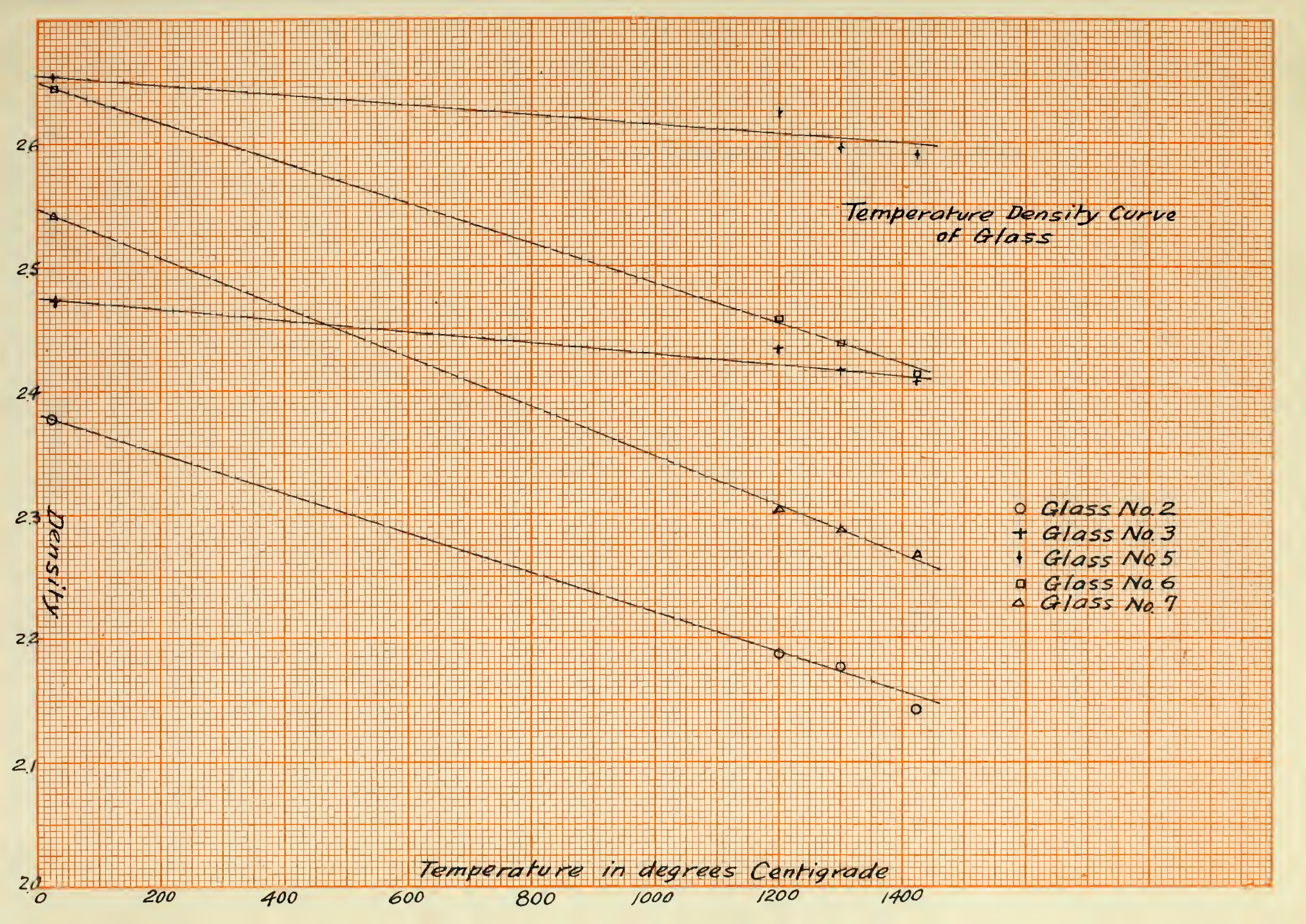
The results from the experiments are tabulated as follows:

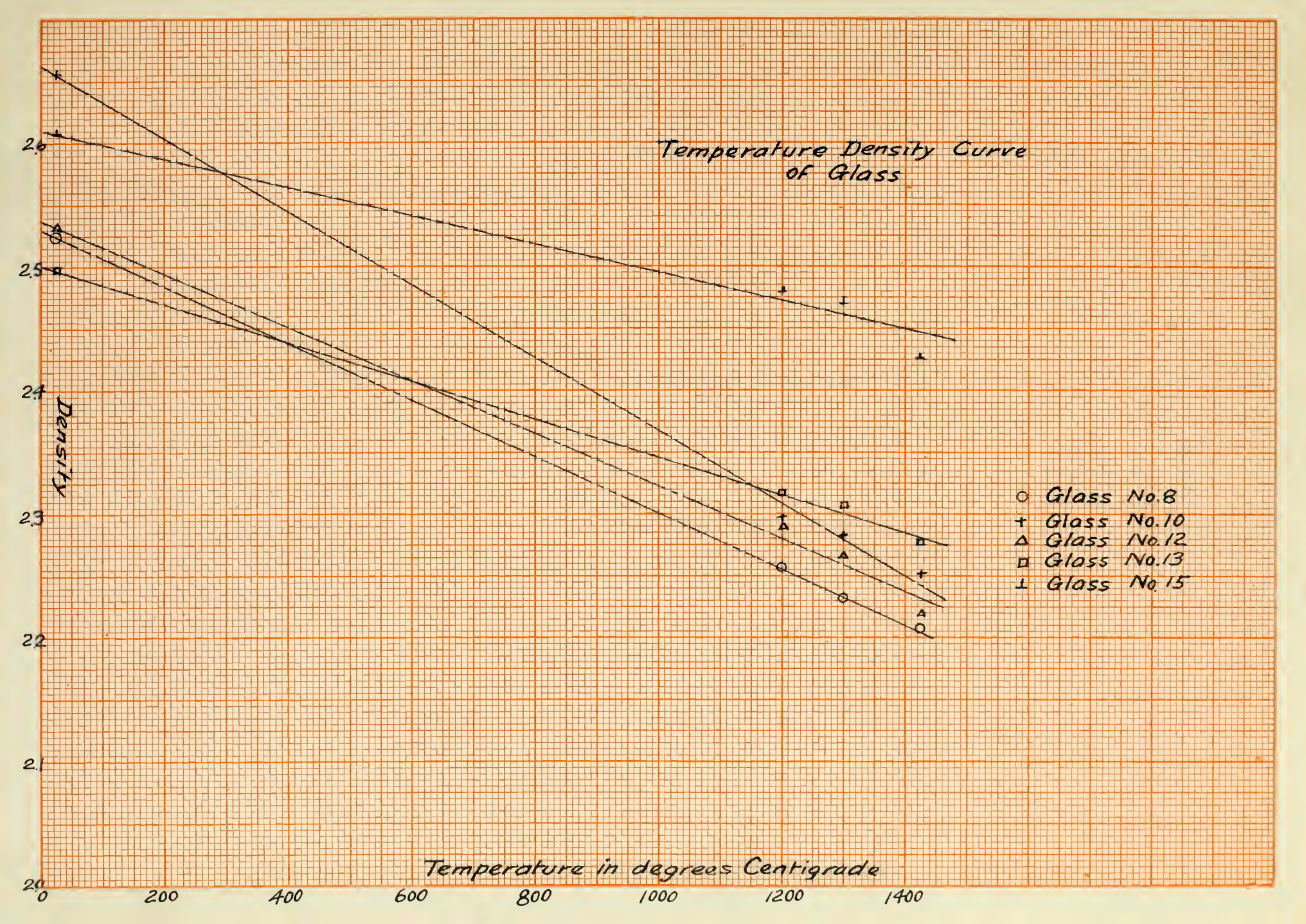
Glass No.	Room Temp. Density	Density at 1200°C	Density at 1300°	Density at 1420°	% of expan. from 20° to 1420°	Coef. of cu. exp. 20° to 1420°
2	2.356	2.187	2.175	2.142	9.04	0.649×10^{-4}
3	2.474	2.433	2.416	2.408	2.67	0.196×10^{-4}
4	2.548	2.282	2.287	2.342	8.08	0.628×10^{-4}
5	2.652	2.626	2.594	2.586	2.49	0.182×10^{-4}
6	2.646	2.459	2.438	2.412	8.85	0.692×10^{-4}
7	2.542	2.304	2.289	2.268	10.77	0.849×10^{-4}
8	2.525	2.251	2.231	2.210	12.48	1.014×10^{-4}
9	2.590	2.257	2.273	2.262	12.65	1.035×10^{-4}
10	2.656	2.292	2.285	2.252	14.80	1.278×10^{-4}
12	2.527	2.295	2.270	2.218	12.23	0.995×10^{-4}
13	2.496	2.316	2.306	2.275	8.85	0.694×10^{-4}
15	2.608	2.480	2.475	2.423	7.08	0.545×10^{-4}
16	2.600	2.398	2.403	2.426	6.74	0.513×10^{-4}

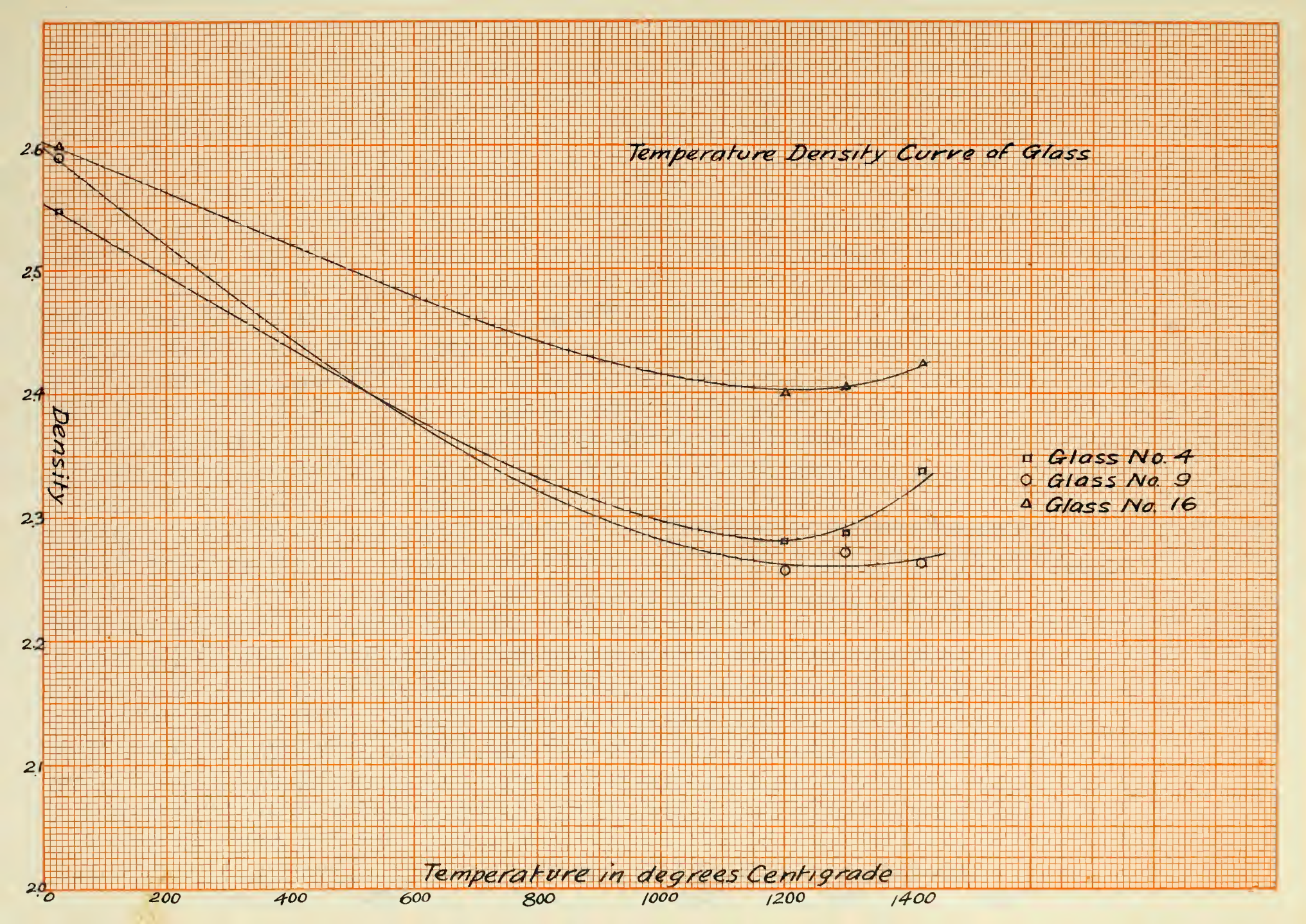
In order to make the results easily understood, two other methods as given below were used, (a) by the temperature density curves and (b) by the composition density model.

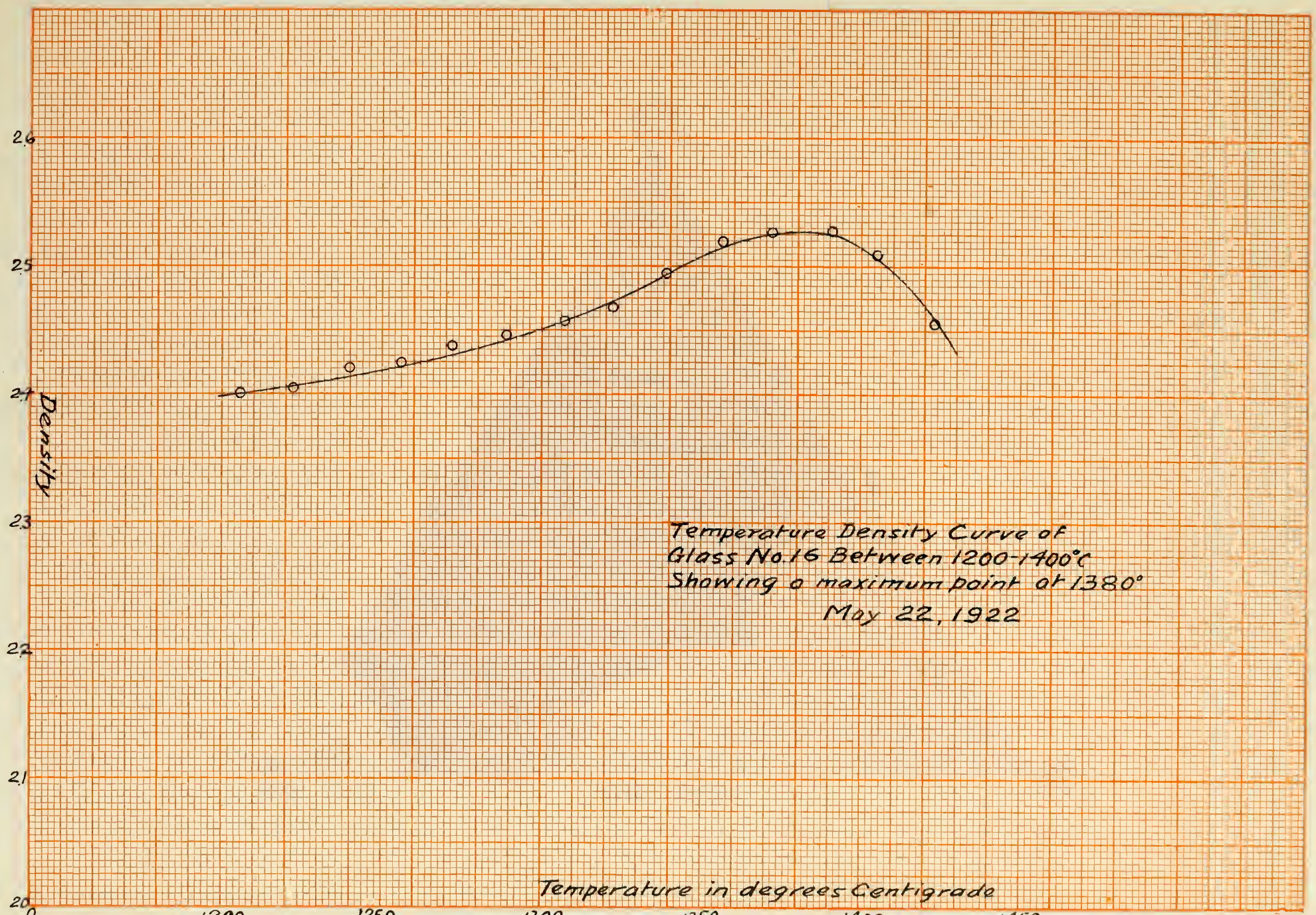
(a) The curves were all drawn to the same scale so as to give a better comparison. One extra curve was drawn for glass No.16. In this case a duplicate was run and more frequent density readings were taken at smaller temperature intervals. This curve shows a maximum density at 1380°C,

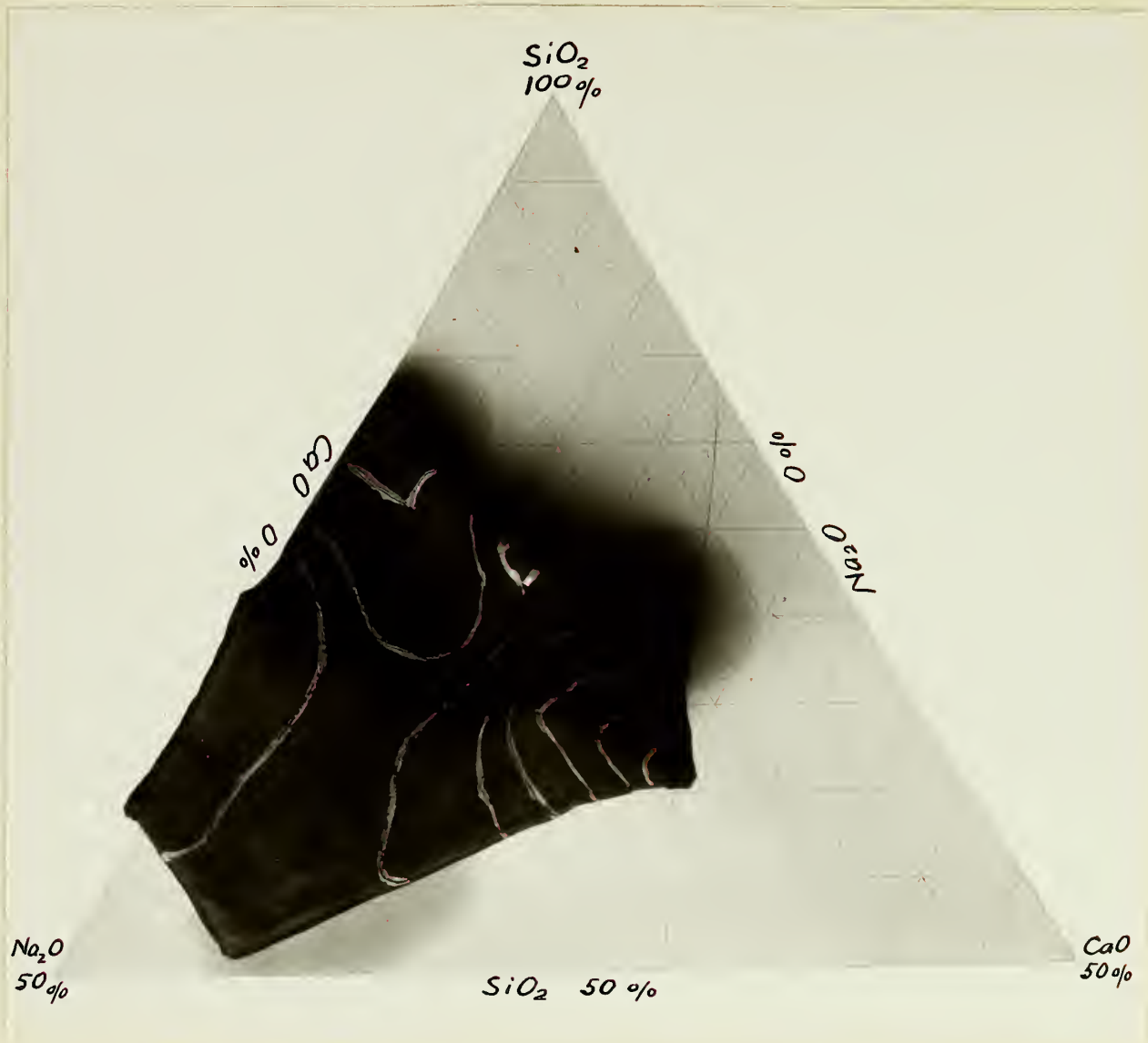
(b) The composition density model was built for the density of the different glasses at 1420°C. The composition of the glass is represented on the triangular coordinate paper. The vertical distance of the model at any point represents the density at 1420° of the glass, having its composition represented by the point. Each centimeter vertical distance of the model represents an amount of 0.1 for the density. As shown on the photograph attached below, the first white horizontal line represents a density of 2.15; the second 2.2, etc., The base of the model represents a density of two.

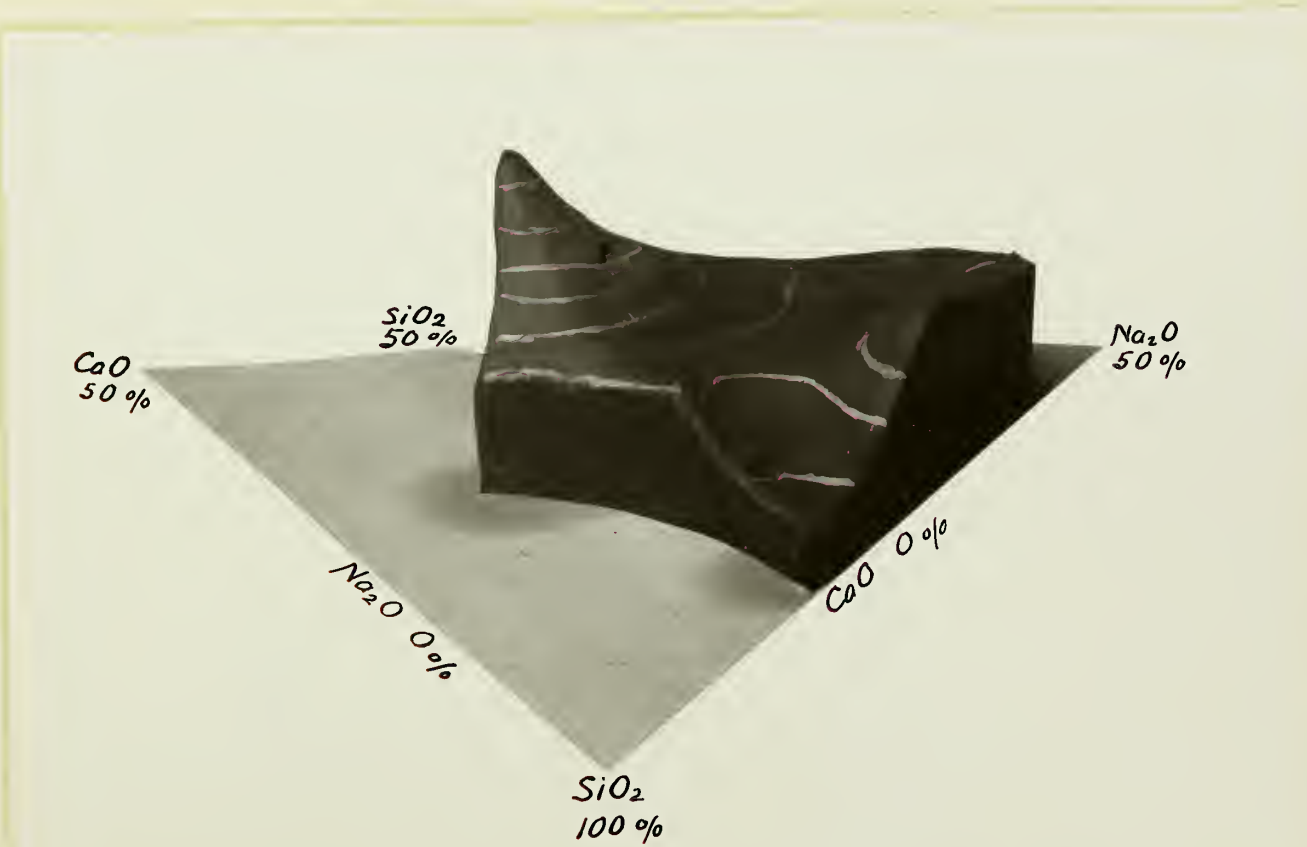

Temperature Density Curve of Glass
Density
Temperature in degrees Centigrade
2.6
2.5
2.4
2.3
2.2
2.1
2.0
0
200
400
600
800
1000
1200
1400
Glass No. 2
Glass No. 3
Glass No. 5
Glass No. 6
Glass No. 7


Temperature Density Curve of Glass
Density
2.6
2.5
2.4
2.3
2.2
2.1
2.0
0
200
400
600
800
1000
1200
1400
Temperature in degrees Centigrade
Glass No. 8
Glass No. 10
Glass No. 12
Glass No. 13
Glass No. 15


Temperature Density Curve of Glass
Density
2.6
2.5
2.4
2.3
2.2
2.1
2.0
0
200
400
600
800
1000
1200
1400
Temperature in degrees Centigrade
Glass No. 4
Glass No. 9
Glass No. 16


2.6
2.5
2.4
2.3
2.2
2.1
2.0
Density
0
1200
1250
1300
1350
1400
1450
Temperature in degrees Centigrade
Temperature Density Curve of
Glass No.16 Between 1200-1400°C
Showing a maximum point at 1380°
May 22, 1922


SiO_2
100 %
CaO
0 %
Na_2O
0 %
Na_2O
50 %
SiO_2 50 %
CaO
50 %


SiO2
50 %
CaO
50 %
Na2O
50 %
Na2O 0 %
CaO 0 %
SiO2
100 %

VI. DISCUSSION.

Accuracy of the Result.- The results do not show much uniformity in the amount of expansion from room temperature to 1400°C nor do they show any indication of the relation between the composition of the glass and the amount of expansion. The duplicates run for a few samples only check to the second place after the decimal. Small errors are unavoidable in making readings of temperature and elongation. Dissolved gases in glass have considerable effect upon the experiment. This difficulty, however, could be overcome by putting the molten glass under vacuum so as to lift the gas out of the mass. But another source of gas buble may arise from the decomposition or volatilization of certain components of the glass. This is shown by an experiment with lead flint glass. The density of the lead flint glass was determined. When the temperature reached 1300°C , gas bubbles began to appear, and as the temperature went up more gas bubbles appeared. At the same time the platinum ball was raised up considerably. This probably was due to the gas bubbles adhering to the ball and tending to rise up to the surface. As the temperature cooled down again, the gas bubbles disappeared gradually until at 1200°C no more bubbles were visible. This phenomenon perhaps was due to the vaporization of arsenic compounds at high temperature. Difficulties of this kind may not be able to be overcome without changing the composition of the glass. Still another source of gas bubbles may be due to the excluded gases

in platinum escaping at high temperature. In high silica glasses the melting range is so high that the glass is still very viscous at 1200°C or 1300°C, and it is no doubt difficult to obtain reliable measurements under these circumstances. For these reasons it is not expected that the results are very accurate. Since the duplicates of a few samples check to the second place after the decimal, the third place after the decimal shown in the table is not of much value.

Glasses No. 4 and No. 16 show a peculiar phenomenon, i.e., as the temperature goes up the density goes up also. A duplicate was run on glass No. 16 and the readings check fairly well. The temperature density curve of glass No. 16 shows a maximum at 1380°C. This may be due to certain errors, but since the two runs check it is not likely that any errors made are merely coincident. Whether or not glasses do have this property needs further investigation.

Jaeger in Holland used a balance suspended over the furnace in determining the density of molten salts. The platinum ball was suspended from the bottom of the pan, the other arrangements being similar to those described above. This method may take longer time to get equilibrium. The spring suspension method has the advantage of simplicity and ease of manipulation. The sources of error due to any effect tending to alter the amount of elongation from the normal value can be eliminated by immediate checking after each run. The disadvantage of this method is that if the two telescopes are not set quite parallel, a small angle will make considerable error in the result.

Suggestions: - Evacuate every glass before each experiment. Keep the molten glass at a certain temperature long enough in order to secure equilibrium before a reading is taken.
Run the temperature up and down through the range at least twice in order to see if the readings check.
Lastly take good care in leveling the two telescopes so that they are exactly parallel. In this way readings checking to the third place after the decimal might be obtained.

VII. SUMMARY

(a) The range of expansion of different soda-lime glass from room temperature to 1400°C is from 2.49% to 14.8%.

(b) The errors in the experiment are mostly due to the behavior of the glass at high temperature and can be removed by evacuating the glass and by prolonged heating.

(c) Whether or not the molten density has a maximum point of density needs further investigation.